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XC-35 GUST RESEARCH PROJECT

ANALYSIS OF GUST MEASUREMENTS

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SUMMARY

Gust size and intensity were measured during the spring and summer of 1941 and 1942 under a wide variety of weather conditions at altitudes up to 34,000 feet. The Army XC-35 airplane was used as the measuring instrument. The gust size and intensity were derived from recorded motions of the airplane and additional data were obtained on meteorological conditions.

The average gust-gradient distance was found to be independent of altitude and increased slightly as the true gust velocity increased. The maximum effective gust velocity appeared to be independent of altitude and was about equal to the design value of 32 feet per second. The treatment of the design gust velocity as a true gust velocity, constant with altitude, cannot be recommended on the basis of these data. Gust frequency per mile of rough air decreased with altitude.

INTRODUCTION

The present design gust load factors are based on an effective gust velocity U_e of 30K feet per second, where K is the effective gust factor (reference 1) for the important gust-gradient distance H of 9 chord lengths (from unpublished data). The basic data for these design requirements have been obtained from two sources: V-G records obtained during normal operations by commercial airlines (reference 2) and airspeed and accelerometer records taken (on an open time scale) during flight tests of several airplanes. Records from these tests were taken at altitudes up to 20,000 feet (previous to flight tests described in reference 3), although the mass of V-G data is not applicable beyond about 15,000 feet.

The data obtained during past investigations (previous to flight tests with the XC-35 airplane in 1941, reference 3) have been accepted for application to operations limited to moderate altitudes. The increase in operating altitudes of both military and commercial airplanes in recent years has raised the question of the applicability of the current gust design standards in this new condition. The question has frequently been raised, in particular, as to whether the design gust velocity should be treated as a "true" velocity or as an "indicated" velocity. The present investigation was undertaken in 1941 to obtain, in part, data applicable to high-altitude operations and to answer this question. The investigation was continued and 19 more flights were made under a wide variety of weather conditions between June and October 1942. The data collected in 1941 were presented in reference 3 and are combined herein with the data obtained in 1942; consequently, the present report supersedes reference 3. The data were acquired with the Army XC-35 airplane flying within a radius of 100 miles of Langley Field, Va. Records of acceleration and airspeed were obtained at altitudes up to 33,600 feet during 1941 and up to 22,500 feet during 1942.

APPARATUS

The XC-35 airplane is a revised model of the Lockheed 10-E built in accordance with specifications of the Materiel Division, U. S. Army Air Corps, and is shown in figure 1. The airplane differs from the model 10-E in that it has a pressurized cabin and engines of greater power. It was designed to have a service ceiling of 35,000 feet. Pertinent dimensions and characteristics of the XC-35 airplane are given in the following table:

Gross weight, pounds	11,139
Wing area, square feet	458.3
Wing loading, pounds per square foot	24.3
Span, feet	55
Length, feet	39
Mean aerodynamic chord, feet	9.23
Center-of-gravity location, percent mean aerodynamic chord	24.4
Tail length, feet	25.5
Elevator area, square feet	31.3

Stabilizer area, square feet	65.4
Aspect ratio	6.6
Taper ratio	3.1

The leading edge of the mean aerodynamic chord is located 15.4 inches behind the leading edge of the wing at the root section.

The use of the airplane as a measuring instrument (reference 4) requires the use of recording instruments to determine the reaction of the airplane to gusts. The instruments carried in the airplane for this purpose were:

(1) NACA air-damped recording accelerometer

(2) NACA airspeed recorder

(3) NACA timer (1-sec. interval)

The accelerometer and airspeed recorders were fitted with magazine film drums and carried sufficient film for 30 minutes of record at a film speed of 1/8 inch per second.

METHOD

The majority of the flights were made in cumuliform clouds. The procedure was to climb to service ceiling, to select a cloud formation for survey, and then to make successive passages through the cloud at various altitudes. During a passage through a cloud, the intent was to maintain level flight. At times, however, the procedure was modified by the pilot in the interests of safety.

TESTS

The airplane was flown whenever conditions appeared conducive to turbulence at relatively high altitudes. As the program was finally arranged, flights and meteorological measurements were made when

(1) Sharp well-defined cold fronts were located in the vicinity of Langley Field

(2) Large cumuliform clouds and local thunderstorms were expected

No flights were made when

(1) Conditions indicated diffused ill-defined cold fronts or when warm fronts and occlusions were expected

(2) Conditions did not indicate the presence of turbulence at high altitude

Because of the limitations of forecasting and weather observations, the conditions encountered during a flight were not always those expected.

During 1942, the service ceiling of the test airplane was reduced to about 24,000 feet by various mechanical difficulties. As a result, the maximum altitudes attained during cloud surveys was considerably less in 1942 than in 1941.

The recording instruments in the airplane were operated only during traverses through clouds or when turbulence was encountered in clear air. Operations continued until the film supply for the recording instruments was exhausted or until no more turbulence was encountered.

RESULTS

Records of acceleration and airspeed were evaluated as described in references 4 and 5 to give the true gust velocity U_t and gust-gradient distance H for each satisfactory acceleration peak. For this report, the minimum acceleration peak evaluated was 0.1g, which is equivalent to an effective gust velocity of 2.2 feet per second at an airspeed of 240 feet per second. Figure 2 shows all the data of this type obtained during the 19 flights in 1942 and figure 3 presents all the data obtained during 37 flights in 1941 and 1942.

In addition to the evaluation of true gust velocities from the relatively limited number of satisfactory cases,

every acceleration peak was evaluated to give the effective gust velocity U_e and the true effective gust velocity U_{e_t}. The evaluation was made from the 1 g line as a datum so that, in this respect, the results are comparable with those obtained from a V-G recorder (references 2 and 5). In the present instance, however, the variation of the weight of the airplane has been taken into account in the evaluation of the data. From the data obtained on each flight during 1942, figure 4 was prepared by plotting the maximum positive and negative values of effective gust velocity from each traverse as a function of altitude. Figure 5 includes all such data obtained during 1941 and 1942. For comparison with the test data, curves representing assumed constant indicated design gust velocity and constant true design gust velocity are included in figures 4 and 5.

The data on effective gust velocities obtained during this investigation are shown in tables I and II for different ranges of altitude. The percentage of total time given in the tables is the percentage of the total record time in rough air. Because the instruments were operated only when turbulence was expected, 7.1 hours of record were obtained in 63 flight hours.

PRECISION

Reference 4 indicates that the evaluation of true gust velocities from airplane reactions is somewhat uncertain unless the airplane has been calibrated in the NACA gust tunnel. Owing to the urgency of other work in the NACA gust tunnel, the XC-35 airplane has not been completely calibrated. Until the calibration has been completed, estimates of the precision for the measured values of the various quantities are as follows:

Airspeed, miles per hour	±4
Acceleration increment	±0.1g
Time scale, seconds	±0.05
Altitude, feet	±100
Gust velocity, percent	±10
Gust-gradient distance H, feet	±15

The value of U_t is dependent upon the magnitude of H and is therefore dependent upon the calibration of the

XC-35 model. By definition, U_e and U_{e_t} are not affected by the calibration.

DISCUSSION

The complete data are in general agreement with the partial results presented in reference 3. Inspection of figures 2 and 3 shows that the largest gust velocities occur with gust-gradient distances larger than 9 chord lengths. The largest values of true gust velocity obtained in 1941 and in 1942 had gust-gradient distances that were almost equal - 230 feet and 218 feet, respectively. Although the largest value of effective gust velocity U_e was obtained in 1942 (fig. 5), the largest value of true gust velocity U_t was obtained in 1941 owing to the nature of the evaluated acceleration peak.

In previous investigations (reference 4 and unpublished data), the largest gusts almost always occurred with gust-gradient distances of about 9 chord lengths. It was pointed out in reference 5 that the effect of the longitudinal stability of the airplane restricts the range of gust-gradient distances "recognized" by the airplane. On this basis and from a general knowledge of the factors involved, the XC-35 airplane appeared to be somewhat less stable than the airplanes previously used for such work. The results of tests in the NACA gust tunnel are needed, however, before these comments can be verified.

The results shown in figures 4 and 5 and tables I and II indicate that, for all practical purposes, the maximum effective gust velocity $U_{e_{max}}$ is independent of altitude. The values of $U_{e_{max}}$ recorded during flight tests are approximately equal to the design gust velocity of 30K feet per second (reference 1) at all altitudes up to 33,600 feet. The test data and curve B of figure 5 show that the assumption of a constant variation of true gust velocity with altitude is not valid. It is interesting to note that the values of $U_{e_{max}}$ in figure 4 tend to increase with altitude up to 21,000 feet; this trend is relatively unimportant since very little data were obtained from 21,000 feet to 22,500 feet and none at all beyond 22,500 feet owing to the decreased service ceiling of the XC-35 airplane.

Although the design effective gust velocity for the XC-35 airplane (curve A, fig. 5) was not equaled for altitudes below 10,000 feet, V-G data (reference 2) obtained below 10,000 feet equal and exceed the design effective gust velocity. Although the most severe conditions that exist in the atmosphere were probably not investigated, the data indicate that the present design requirements are satisfactory. Applied accelerations from which the data were obtained were not so large as the design applied gust load factor, inasmuch as the pilot operated the airplane to maintain a reasonable speed.

In order to determine the influence of altitude and gust intensity on the gust-gradient distance H, the available data for 1942 and 1941 were used to obtain the average value of gust-gradient distance H_{av} for given ranges of altitude and gust velocity (fig. 6). When only one or two points were available, the data were not used to determine H_{av}. The results indicate that, for altitudes up to 34,000 feet, the gust-gradient distance H is independent of altitude and increases slightly as the true gust velocity U_t increases.

Since the results indicate that the maximum effective gust velocity is independent of altitude, it is desirable to determine whether the gust frequency is a function of altitude. Figure 7, prepared from the data of table II, shows that the gust frequency per mile of rough air decreased with altitude, particularly above 18,000 feet. Extrapolation of the curve indicates a negligible gust frequency above about 40,000 feet, a reasonable conclusion for the climatic conditions of eastern Virginia. If the smooth air that is normally encountered by an airplane is neglected, up to 20,000 feet there appears to be no decrease in gust frequency per mile of rough air. The gust-frequency scale of figure 7 is not significant for statistical studies since the low categories of gust velocity have not been included.

CONCLUSIONS

Data obtained from measurements of gust size and intensity under a variety of weather conditions and at altitudes up to 34,000 feet indicated the following conclusions:

1. The average gust-gradient distance was independent of altitude for altitudes up to 34,000 feet and increased slightly with gust intensity.

2. Effective gust velocities equal to and exceeding the design value of 32 feet per second were encountered at altitudes up to approximately 34,000 feet.

3. The maximum effective gust velocity was independent of altitude.

4. The treatment of the design gust velocity as a true gust velocity constant with altitude cannot be recommended on the basis of the data presented.

5. Gust frequency per mile of rough air decreased with altitude.

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TABLE I

FREQUENCY DISTRIBUTION OF EFFECTIVE

GUST VELOCITY FOR DIFFERENT RANGES OF ALTITUDE

[Data obtained during 1942]

U_e (fps) \ Altitude range (ft)	0 to 4000	5000 to 9000	10,000 to 14,000	15,000 to 19,000	20,000 to 24,000	0 to 24,000
0 to 4	27	518	193	172	60	970
4 to 8	57	1082	430	581	137	2287
8 to 12	18	325	160	236	94	833
12 to 16	1	66	57	91	34	249
16 to 20		15	17	38	13	83
20 to 24		1	4	10	10	25
24 to 28		2	2	2	3	9
28 to 32			1	3	1	5
32 to 36					1	1
36 to 40				1		1
					Total	4463
Record time (percent total time)	3.5	44.2	16.1	27.6	8.6	----

TABLE II

FREQUENCY DISTRIBUTION OF EFFECTIVE

GUST VELOCITY FOR DIFFERENT RANGES OF ALTITUDE

[Data obtained during 1941 and 1942; total record time, 7.1 hr]

U_e (fps) \ Altitude range (ft)	0 to 4000	5000 to 9000	10,000 to 14,000	15,000 to 19,000	20,000 to 24,000	25,000 to 29,000	30,000 to 34,000	0 to 34,000
0 to 4	217	622	267	343	109	102	43	1603
4 to 8	340	1322	571	760	354	449	215	4011
8 to 12	75	351	233	335	198	274	161	1627
12 to 16	10	70	89	129	109	75	51	533
16 to 20	0	15	29	48	41	34	17	184
20 to 24	0	2	8	15	14	15	7	61
24 to 28	1	2	2	5	6	6	4	26
28 to 32			4	4	1	3	1	13
32 to 36			1	1	1			3
36 to 40				1				1
							Total	8061
Record time (percent total time)	6.7	29.3	12.3	17.3	11.6	14.0	8.8	----

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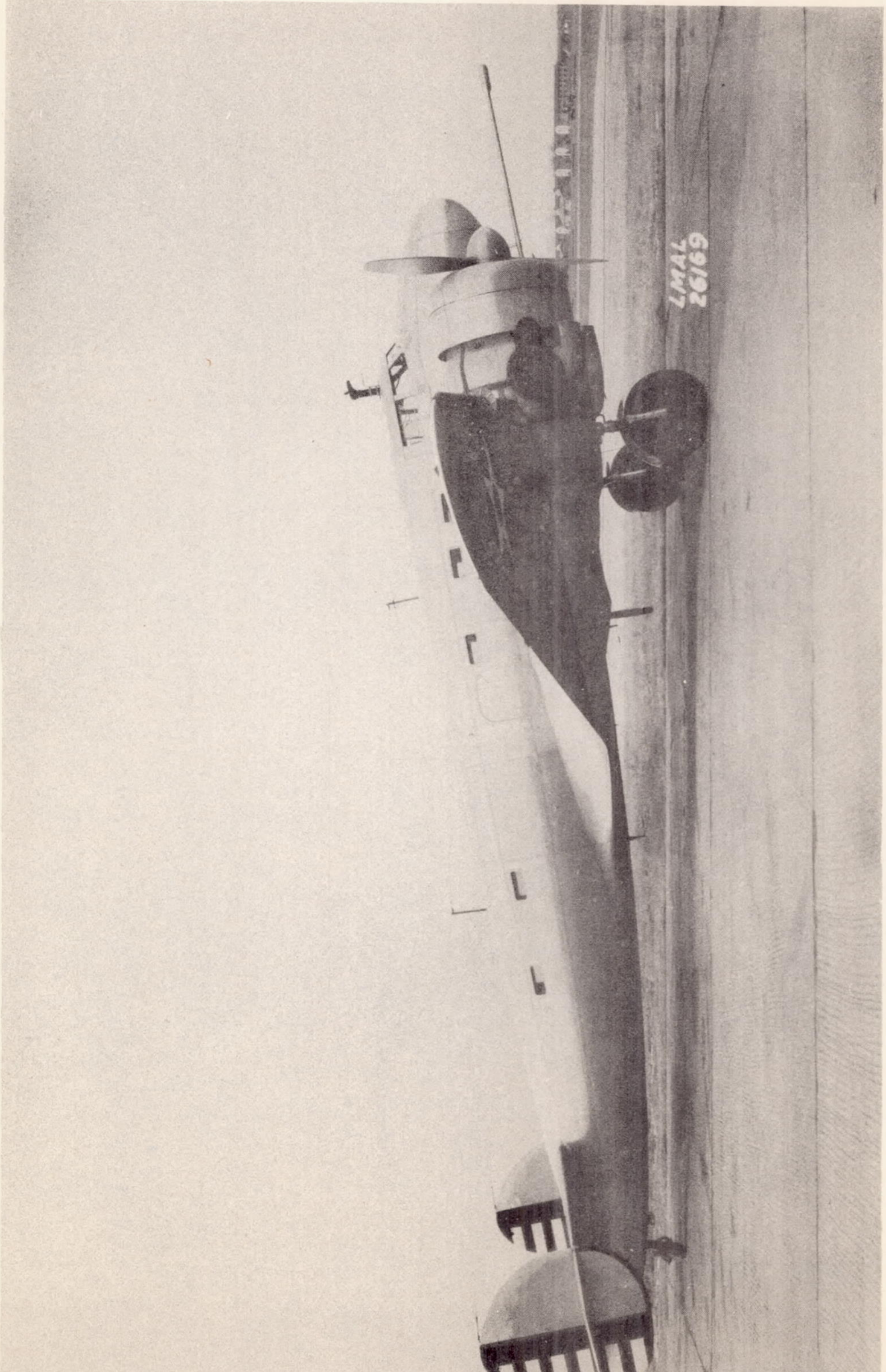

Figure 1.- Side view of XC-35 airplane.

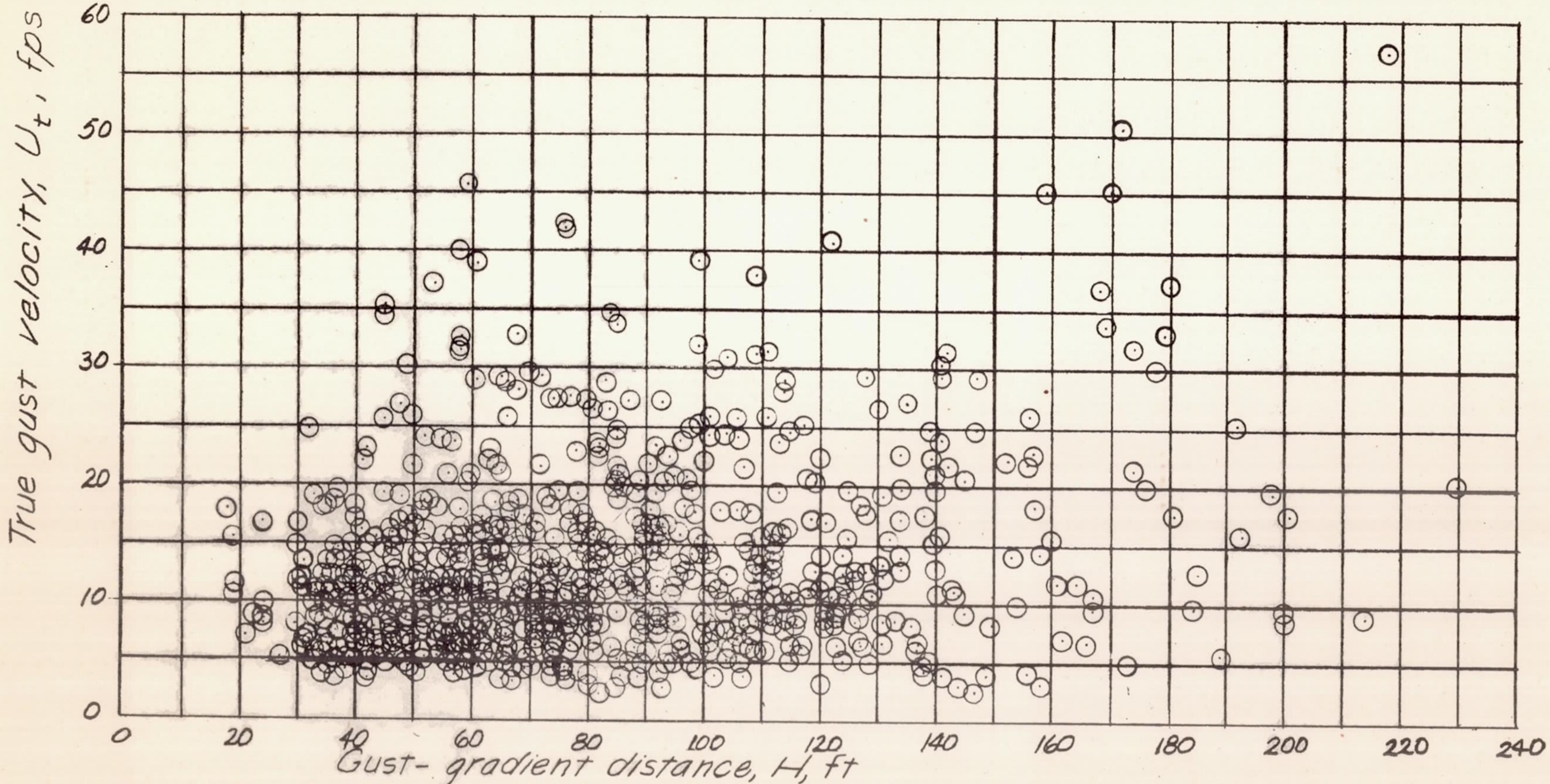

Figure 2.- True gust velocity U_t as a function of the gust-gradient distance H. (Data obtained in 1942.)

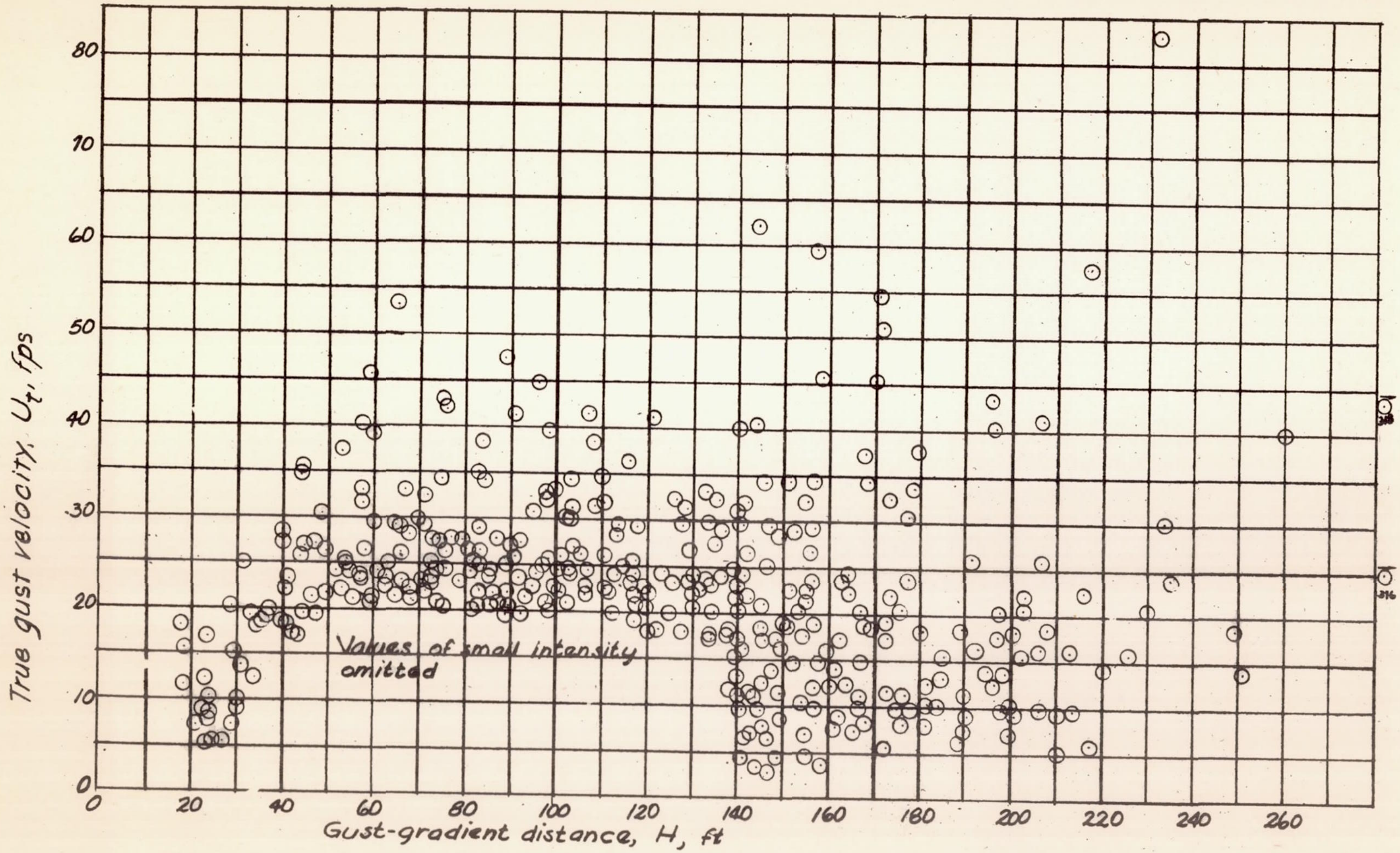

Figure 3.- True gust velocity U_t as a function of the gust-gradient distance H. (Data obtained in 1941 and 1942.)

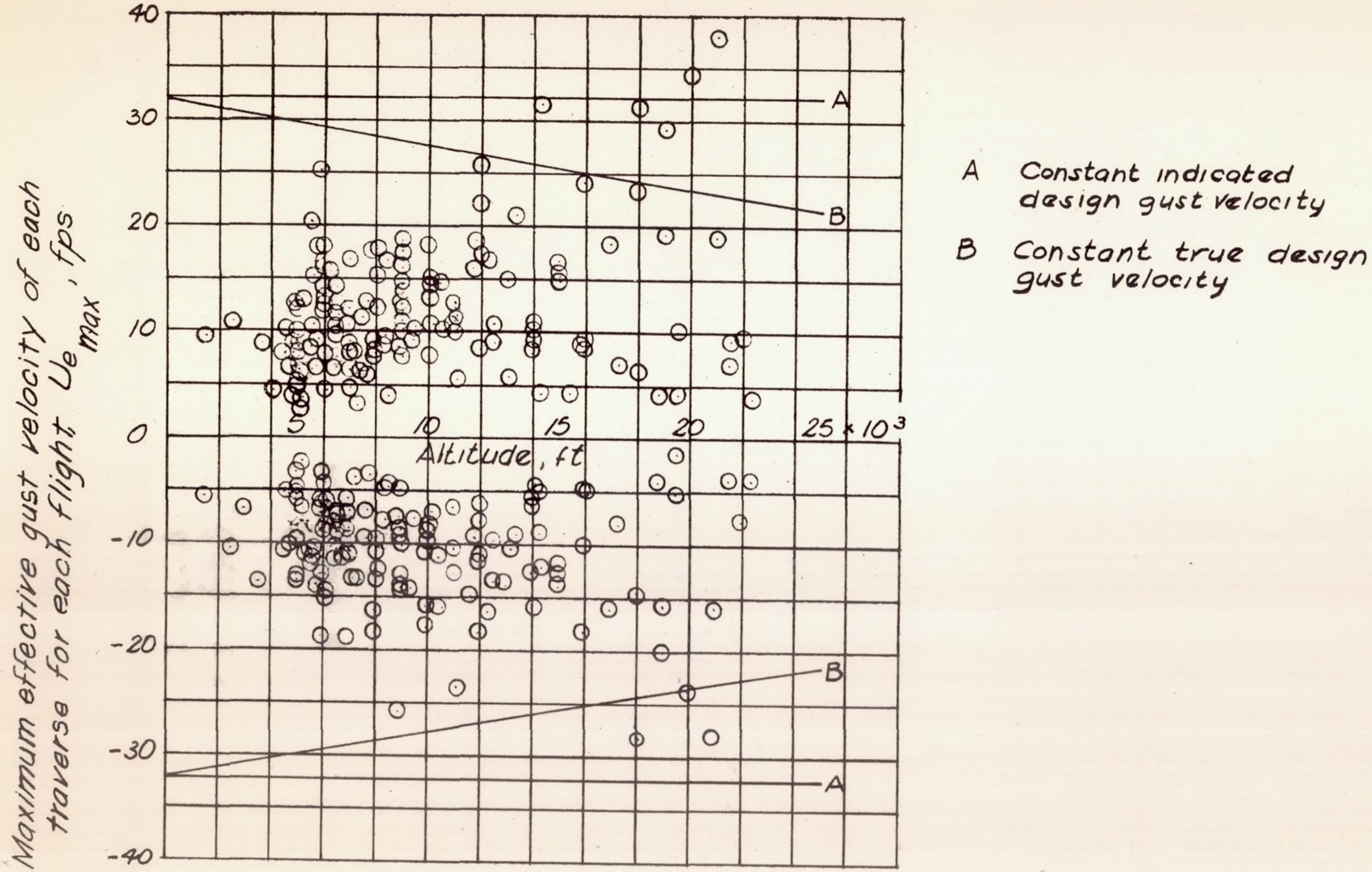

Figure 4.- Maximum effective gust velocities for each traverse as a function of altitude. (Data obtained in 1942)

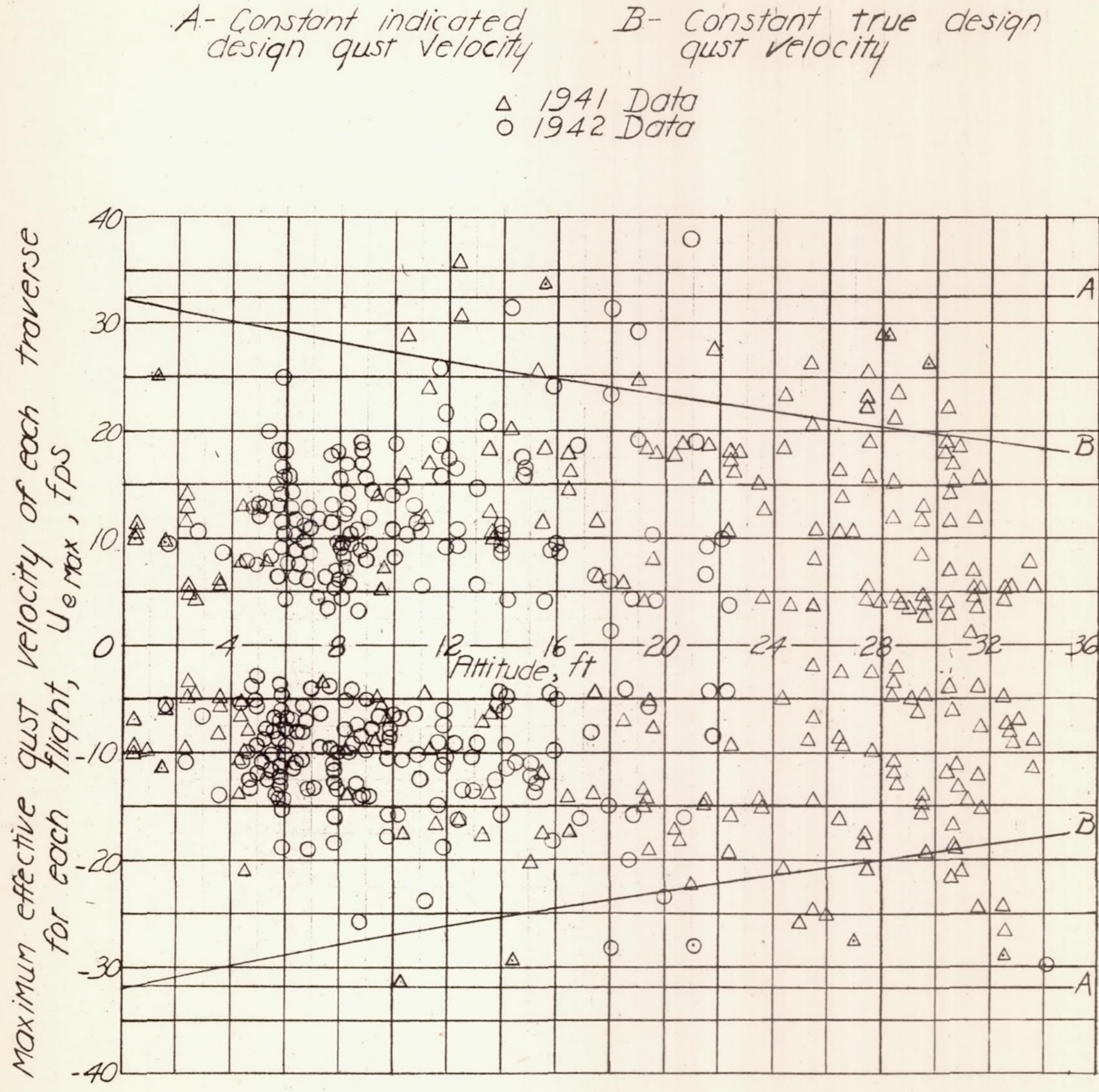

Figure 5.- Maximum effective gust velocities for each traverse as a function of altitude. (Data obtained in 1941 and 1942.)

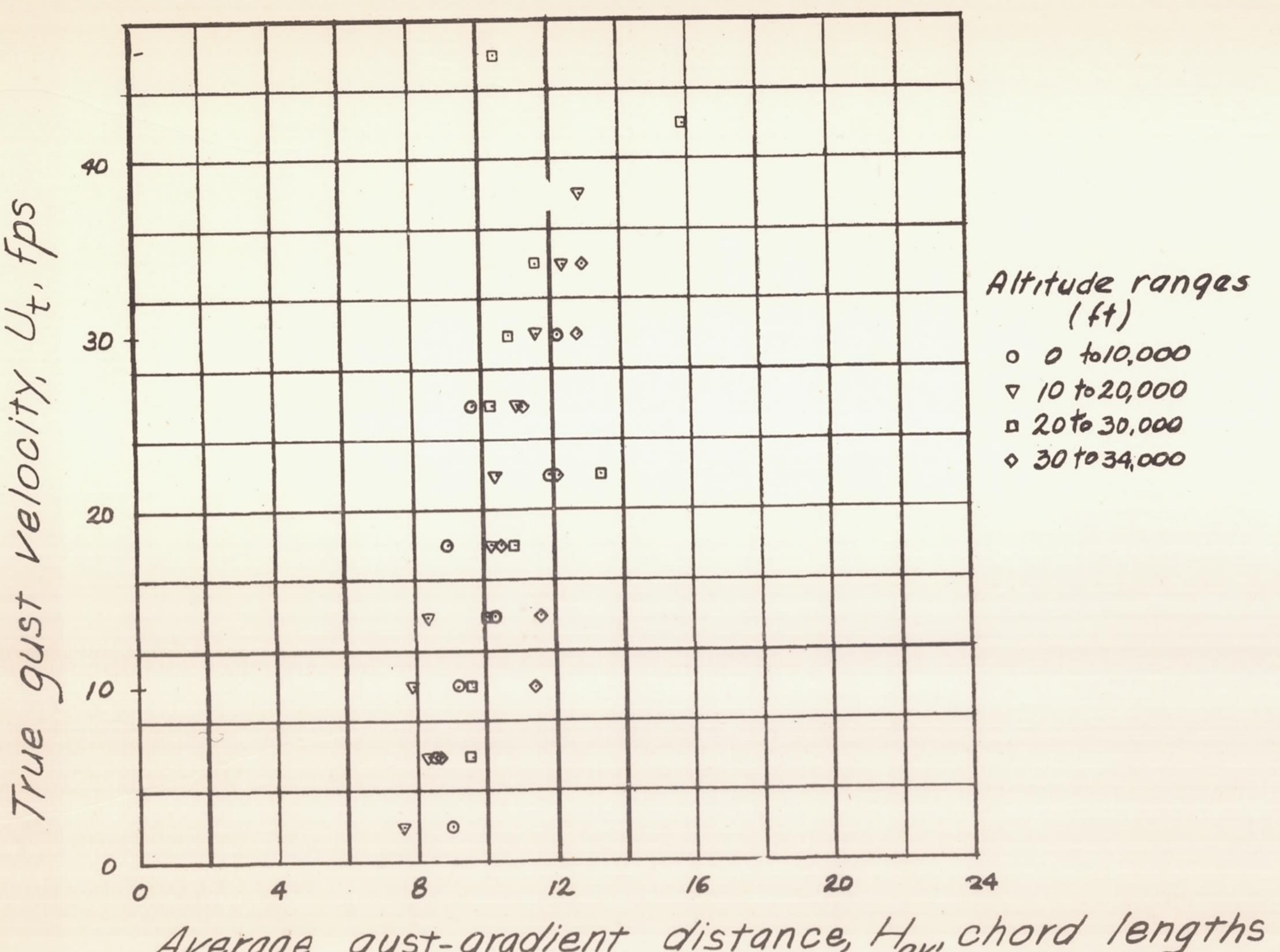

Figure 6.- Variation of average gust-gradient distance with true gust velocity. (Data obtained in 1941 and 1942)

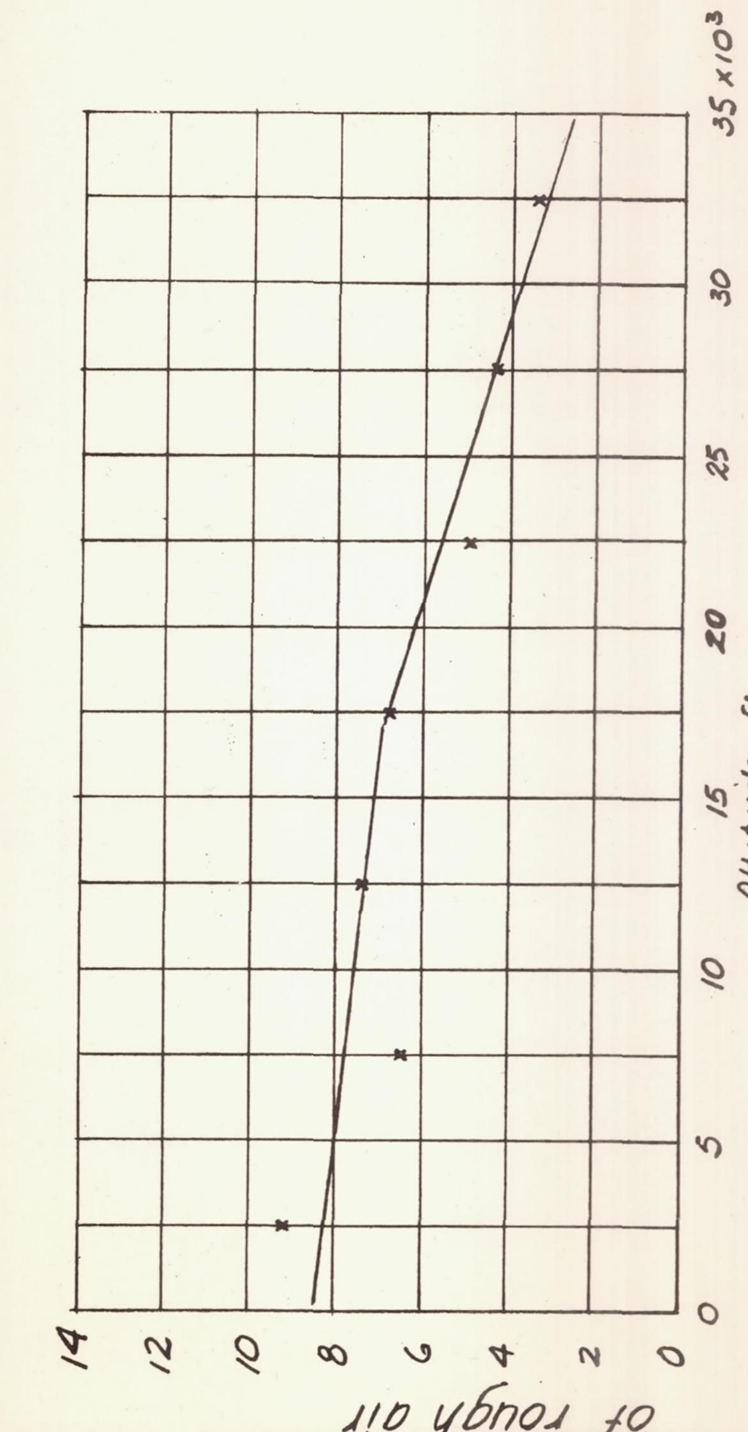

Figure 7.- Gust frequency per mile of rough air as a function of altitude.